THE GEOGRAPHICAL WORK OF DR. M. A. VEEDER

By ELLSWORTH HUNTINGTON

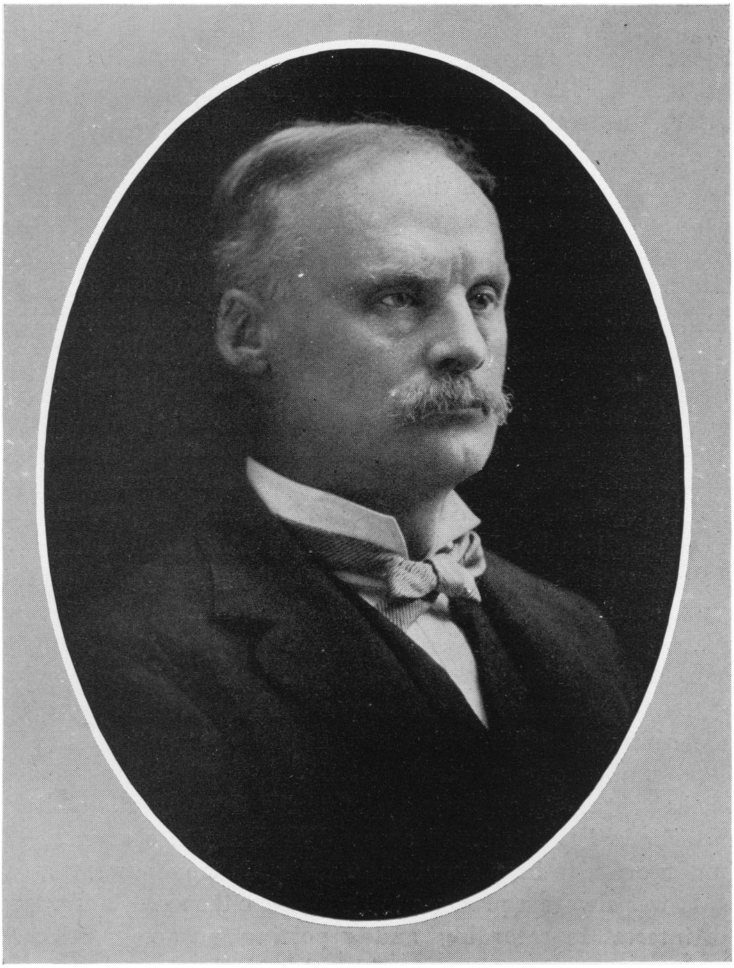
In his "Elegy Written in a Country Churchyard" Gray mourns that

> Some mute inglorious Milton here may rest,
> Some Cromwell guiltless of his country's blood.

Today the poets and reformers seem to make their voices heard in almost every village. The careful, unostentatious scientist is the man most apt to do his work unheralded and unrewarded. There is perhaps no greater economic waste than that which condemns a man of great originality to spend his time in the ordinary round of common duties rather than in carrying on the so-called impractical investigations which are the essential foundation of all the so-called practical advances. Mendel was such a man, and his work on heredity was nearly lost because in his quiet, retired life the great biologist did not have the opportunity to make his influence felt. How vastly poorer the world would be without his suggestive ideas, which form the basis of eugenics and are destined to be one of the greatest factors in uplifting the human race!

Similar men have doubtless worked in other fields, and their ideas may still be waiting to be utilized. One such man has recently come to my attention. I do not mean that he is another Mendel, for only time can determine that. I can say with confidence, however, that in the study of meteorology I have come upon no writings which have stimulated me more than those of Dr. M. A. Veeder. His hypotheses may prove wrong, but that will not destroy the stimulating character of his broad and original ideas.

In January, 1916, Dr. Henryk Arctowski sent me a postal card advising me to read a certain article which he evidently thought important. A few days later I went to the library. Before taking the card from my pocket I looked up some other matters and came upon an article entitled "Magnetic Storms and Sun Spots" by M. A. Veeder. It was a single large sheet, the abstract of an article presented at the Springfield meeting of the American Association for the Advancement of Science in 1895. The brief text and especially the accompanying table were so interesting that I studied them for an hour, and determined to see what more I could find by the same author. Then I took out the postal card and found that it contained a reference to another article by the same man. Dr. Arctowski and myself were so interested in these articles that we wrote to Dr. Veeder at his home in Lyons, N. Y., but found that he had died shortly before. His family, however, sent us copies of his articles and later, at our request,



M. A. VEEDER, M.D.

Born at Ashtabula, Ohio, November 2, 1848; died at Lyons, N. Y., November 16, 1915.

a considerable number of his original tables, scientific letters, and unpublished articles. These proved so suggestive that parts of them are to be published in this *Review*.

Dr. Major Albert Veeder was born at Ashtabula, Ohio, November 2, 1848, and died at Lyons, N. Y., on November 16, 1915. He took his B. A. degree at Union College, Schenectady, in 1870 and later his M. A. In 1878-79 he studied at Leipzig, and after a medical course at the University of Buffalo took his M. D. degree in 1883. He then practiced medicine in Lyons, N. Y., the rest of his life. This modest, unassuming, but highly gifted man should never have been obliged to get a living by practicing medicine. He ought to have been connected with some great scientific institution where he would have been free to carry on his researches untrammeled by anxiety about the support of his family. His mind was extraordinarily fertile in ideas, not only in respect to his own profession but along other scientific lines. He appears to have been the first to publish an article clearly setting forth the now well-accepted idea that typhoid germs are carried by flies, and it was upon his advice that the medical department of the United States Government adopted its successful policy of preventing the spread of typhoid fever in Cuba and in the southern camps of our soldiers during the Spanish War. He was also a pioneer in advocating the open-air treatment of tuberculosis and was perhaps the first adequately to explain it. In addition to such work Dr. Veeder was interested in geology and wrote a number of articles about the mound builders and about the rock structure and glaciation of his home district in western New York.

Dr. Veeder's chief scientific interest, however, was in meteorology. In the latter part of the seventies he began a study of the aurora. He not only made observations himself and utilized the reports of the Weather Bureau and similar organizations, but he also started a plan for cooperative observations in all parts of the world. In connection with Peary's polar expeditions, he distributed over 5,000 blanks to observers in all the continents, in order to have simultaneous records from as wide a region as possible. It was always a pleasure to Dr. Veeder that people in many lands took such interest in recording and reporting auroras for him. These aurora studies led Dr. Veeder to consider the relation between the activities of the sun and the earth. The result was that by 1895 he had framed an hypothesis which may possibly prove to be one of the most important contributions not only to meteorology but to astronomy. Nevertheless, Dr. Veeder's work has received little recognition. This is partly because his more important articles were published in journals having only the most limited circulation. The nature of these journals made it impossible to present the great body of facts which he had accumulated. So far as his work appeared in newspapers or more widely read magazines it took the form of conclusions without the facts on which they were based. Moreover,

Dr. Veeder was unfortunate in not being able to arouse the interest of other students of meteorology. In letters dating from 1886 to 1895 he again and again urged the Weather Bureau to give his electro-solar hypothesis a trial. His efforts were fruitless. He was so far ahead of his time that the scientific world was not yet ready for his hypothesis. Today, however, the work of such men as Newcomb, Köppen, Hann, Bigelow, Arctowski, Hildebrandsson, Kullmer, and many others makes it clear that the time is ripe to test on a large scale every reasonable suggestion as to the connection between solar and terrestrial activities.

Up to 1896 Dr. Veeder spent as much time on his researches as a busy physician's life would allow, averaging perhaps an hour or two a day. From 1893 to 1895 he devoted extra time to it, but then gave it up almost entirely, although its problems fascinated him as much as ever. He was sure that his conclusions were substantially correct and that the subject was of the greatest interest and importance and far from being exhausted. He was disappointed that his ideas were not more widely accepted, knowing as he did their practical importance and wide application. Yet he realized that they would need time for recognition and he looked forward to their being carried on by others more favorably situated than was he.

As to giving up his researches he wrote on December 5, 1895: "If I could simply have held my own professionally and financially, doing this work as best I could at odd moments, I should have been satisfied. This has not proved to be possible. Not being of independent means and leisure I feel compelled to discontinue. Of course, if I were to theorize or speculate rather than sift evidence laboriously collected and collated it would be easy, but the course I have been following depends upon work, and a good deal of it, which I cannot continue, situated as I am." He found that his interest in these outside matters was used against him to injure him in his medical practice.

The paper on "Magnetic Storms and Sun Spots," which first attracted my attention, was to be Dr. Veeder's valedictory, unless some way should open to give him the leisure and means to carry on his work. No such way opened, and he was compelled most reluctantly to relinquish it. It is one of the lamentable wastes of our American system that a man with such unusual originality and with a passion for the laborious, accurate study of maps and figures should have been forced to give up the work that he loved just at the time when he was capable of doing the most effective service. It is truly astonishing to find how he has antedated more recent workers in investigations and conclusions which they regard as among their most important work. For instance, he fully appreciated Arctowski's fruitful idea as to pleions, or waves of excessive heat, pressure, or moisture. Dr. Veeder also saw clearly that storm tracks shift back and forth in latitude in harmony with sun-spots, as has been shown more recently by Bigelow, Hildebrandsson, Kullmer, and others. He also put into permanent

form my own idea that there are two kinds of solar variations, one thermal and the other of some other nature. His conclusions as to auroras also antedated those of other investigators who have since confirmed his results.

It is somewhat surprising to find that Dr. Veeder's most important hypothesis was by no means the one with which his published writings deal most fully. He apparently attached greater weight to his minute investigations of auroras than to his general meteorological hypothesis.

In all his work Dr. Veeder insisted that ultimately its results would be of great practical value. Nevertheless, he avoided a danger into which many more recent investigators have fallen. He discouraged the idea that his conclusions would immediately result in a great change in our present methods of forecasting the weather. He held that changes in the sun exert their effect chiefly by intensifying the pressure of anticyclonic areas. This in turn apparently strengthens cyclonic storms and causes their paths to vary. Unfortunately the terrestrial changes appear to take place at so short an interval after the solar changes that it is doubtful whether we can know what is happening on the sun in time to make predictions for the earth. If he is right, however, we shall at least know *why* changes of weather take place and why our weather predictions so often fail. Whatever may be the ultimate fate of Dr. Veeder's hypothesis a careful study of his writings cannot fail to be stimulating.

The work on the auroras is described in the articles listed below. His main hypothesis is explained on the following pages in an hitherto unpublished article by Dr. Veeder, together with extracts from some of his letters. The main point of his hypothesis is that terrestrial weather is dependent upon solar changes, to which he adds the conclusion that the relation is presumably electrical instead of thermal. So revolutionary an hypothesis needs an enormous amount of testing. Since becoming acquainted with Dr. Veeder's work I have attempted to begin this testing process. After making detailed comparisons between the solar changes and barometric gradients of over 2,500 individual days I have come to the conclusion that Dr. Veeder is essentially right in two important respects. In the first place, solar changes appear to be closely followed by terrestrial changes. In the second place, the connection between the solar and terrestrial phenomena appears to be due in part to some cause other than heat.

Like everyone whose ideas extend beyond those of their fellows Dr. Veeder made mistakes. For example, he seems to ascribe undue importance to the *marginal* location of disturbances of the sun's photosphere. In this particular matter his earlier writings are apparently more correct than later ones. It is easy to see how his mistake arose. The appearance of solar disturbances on the sun's margin when they are brought into sight by rotation is the most important agency in causing the activity of the visible portion of the sun's surface to vary from day to day. My own investigations, however, show that changes in other parts are equally or

more important, provided they are of equal magnitude. In another respect Dr. Veeder perhaps went further than the facts warrant. He assumes that changes in the electrical field of the sun are sufficiently strong to produce the observed terrestrial changes in barometric pressure. Perhaps this is true, but it has not yet been demonstrated. It may be that the connection between the earth and the sun is due to some other cause not yet understood.

The value of Dr. Veeder's conclusions can be truly appreciated only when his methods are understood. As already indicated he made the mistake of giving too much space to his conclusions and too little to his facts. A study of his original tables and manuscripts, however, makes it clear that he rarely or never made a statement which is not based on a considerable body of evidence. His table of auroras, for instance, is a huge document perhaps twenty feet long and involving a vast amount of most assiduous labor. The way in which parts of it are recopied and marked in pencil shows what great pains he took in testing first one interval and then another to determine whether auroras really show a periodicity. He finally decided that the auroras show a periodicity of 27 days, 6 hours, and 40 minutes. The fact that he came to this conclusion without knowing that his result was within four minutes of the period of solar rotation determined independently on the basis of sun-spots is strong evidence of the reliability of his work.

Along other lines similar care is evident. The following extract from a letter dated July 26, 1895, gives an idea of the methods which finally led to the hypotheses presented on later pages of the *Review*. "I have two record books, one of which serves as a journal, and the other as a ledger. The pages of the journal are numbered with the ordinary calendar dates and likewise with the numbers of the days of the synodic rotation period of the sun. At the top of each page there is a diagram of the sun's disc upon which are noted the location of all spots and faculae seen. Upon the pages underneath are entered notes regarding thunderstorms, auroras, earth currents, and magnetic perturbations, together with as full an account as possible of any evidences of storm intensification or its absence. The other book, which serves as a ledger, is simply a very long-paged record book having many lines to the page. At the tops of the pages are placed the numbers of the days of the synodic rotation period of the sun in regular order from 1 to 28 [the 28th day being used only every fourth time] and underneath are placed summary references to what appeared at successive returns, so that it is possible at a glance to determine what conditions were present on any day of the period at many returns. By the use of such a system of tabulation of data it becomes possible to state the probabilities for a day or two in advance in reference to the behavior of the conditions shown upon the daily weather maps."

LIST OF THE MORE IMPORTANT ARTICLES BY M. A. VEEDER ON THE RELATION BETWEEN SOLAR AND TERRESTRIAL METEOROLOGY

Solar Origin of the Aurora. *Sidereal Messenger,* November, 1889. 4 pp.

The Relation between Solar and Terrestrial Phenomena. Lyons, N. Y. 8 pp.

The Aurora. *Proc. Rochester Acad. of Science,* Vol. 1, pp. 19-25. 1889.

The Forces Concerned in the Development of Storms. *Proc. Rochester Acad. of Science,* Vol. 1, pp. 57-63. 1890.

The Zodiacal Light. *Proc. Rochester Acad. of Science,* Vol. 1, pp. 137-146. 1891. With table showing "Periodicity of Auroras."

Solar Electrical Energy Not Transmitted by Radiation. *Proc. Rochester Acad. of Science,* Vol. 2, pp. 245-254. 1892.

Thunder Storms. *Proc. Rochester Acad. of Science,* Vol. 2, pp. 134-148. 1893. With table showing "Periodicity of Auroras."

The Source of Solar Heat. *Trans. Astron. and Phys. Soc. of Toronto,* 1893.

Thunder Storms, Auroras, and Sun Spots. *Amer. Meteorol. Journ.,* Vol. 10, 1892, pp. 105-107.

Periodic and Non-Periodic Fluctuations in the Latitude of Storm Tracks. *Trans. Internatl. Congr. of Meteorol. at Chicago,* 1893. 7 pp.

An International Cipher Code for Correspondence respecting the Aurora and Related Regions. *Trans. Internatl. Congr. of Meteorol. at Chicago,* 1893.

Magnetic Storms and Sun Spots. Abstract of paper presented at Springfield meeting of the American Association for the Advancement of Science, 1895. 1 p., with table.

Sun Spots and Auroras. *Canadian Annual,* 1896, published as a supplement to the *Muskoka Herald,* Bracebridge, Ontario.

Magne-Crystallic Action and the Aurora. *Popular Astronomy,* No. 113 (March, 1904). 3 pp.

The Relation between Sun Spots and Auroras. *Astronomy and Astrophysics,* No. 105.

Solar Electro-Magnetic Induction. *Astronomy and Astrophysics,* No. 113, 1913.

THE RELATION BETWEEN SOLAR AND TERRESTRIAL METEOROLOGY

By M. A. VEEDER

Part I—The Observational Basis

(A) INTRODUCTION

By Ellsworth Huntington

Meteorology can never stand upon a firm basis until the perennial question of the relation between solar and terrestrial changes is settled. Where there is so much smoke it seems as if there must be some fire. Year by year there is apparently a growing tendency toward the belief that somehow changes in the sun's atmosphere are the direct cause of the changes in the earth's atmosphere which give rise to what we call weather. Most of the work along this line has been done within the past quarter of a century. Nevertheless, before that time a substantial beginning had been made. It is not improbable that some of the hypotheses proposed a generation ago may prove the key to our present problem. Among the

hypotheses offered in explanation of the elusive but seemingly genuine connection between the earth and the sun none is more carefully elaborated or more full of suggestions for future work than that of Dr. M. A. Veeder. Many of his results have never been published, and others have been published merely as conclusions without the abundant basis of observed facts on which they are founded.

The following pages contain portions of several articles and letters written by Dr. Veeder between 1888 and 1892, but hitherto unpublished. The reader will understand them better if he reads the preceding sketch of Dr. Veeder's career. The articles here printed are reproduced as they appear in Dr. Veeder's manuscripts, with no changes except that perhaps ten words are altered for clearness and certain portions which are now superseded or which are not directly concerned with meteorology have been omitted. Doubtless Dr. Veeder would write differently if he were doing his work today, but his facts still stand and his conclusions are worthy of careful study.

In order that the reader may have a background for the following articles he should bear in mind certain conclusions now generally accepted which were reached by Dr. Veeder independently before others had realized their importance. One of these is thus summed up in the Encyclopædia Britannica by Dr. Chree, director of the Kew Observatory: "That there is an intimate connection between aurora when visible in temperate latitudes and terrestrial magnetism is hardly open to doubt. A bright aurora visible over a large part of Europe seems always accompanied by a magnetic storm and earth currents, and the largest magnetic storms and the most conspicuous displays have occurred simultaneously." Although the cause of the secular variation of the earth's magnetic field is not yet understood, it appears certain that the range of diurnal inequality, that is, the temporary variations of the magnetic forces from hour to hour and minute to minute, bear an intimate relation to changes in solar activity as displayed in sun-spots. For auroras a similar relation prevails, as appears in Table I,

TABLE I—AURORAS AND SUN-SPOTS

NUMBER OF YEARS	SUN-SPOT NUMBERS	TOTAL AURORAS	AVERAGE NUMBER OF AURORAS PER YEAR IN SCANDINAVIA
(12)	0.0-6.8	350	29.9
(12)	7 0-11.3	700	59.8
(12)	12.2-16.6	738	61.5
(12)	17.1-28.1	765	63.8
(11)	30.0-36.8	812	73.8
(12)	37.3-45.0	983	81.9
(12)	45.0-54.2	995	82.9
(12)	54.8-66.5	1024	85.3
(12)	66.5-83.4	1279	106.6
(11)	84.8-101.7	1241	112.8
(12)	103.2-154.4	1390	115.8

which I have prepared on the basis of the figures given in the Encyclopædia Britannica for the years 1749 to 1877. These years have been divided into

groups of twelve (in two cases, eleven) years each on the basis of the sun-spot numbers for the year. For instance, the first group includes twelve years having sun-spot numbers ranging from 0 to 6.8. The next group contains the 12 years with the next higher spot numbers, from 7.0 to 11.3. The auroral data show the number of auroras seen in Scandinavia. An inspection of the table shows that as the sun-spot numbers increase, the auroras also increase. Individual years sometimes depart from this rule, but there is no departure when a considerable number of years are averaged. The departures are probably due to the fact that Scandinavia includes only an insignificant portion of the earth's surface and many auroras may occur without being visible there.

Another respect in which both terrestrial magnetism and auroras show a relation to the sun is in their daily period. I have prepared Table II

Table II—Diurnal Variation of Auroras and Terrestrial Magnetism

Hour	A Diurnal Inequality of Magnetic Declination in minutes of arc at six stations north of Latitude 40° N. (+=westward declination)	B Diurnal Inequality of Horizontal Force at six stations north of Latitude 40° N. (1=.00001 C. G. S.)	C Number of Auroras in November, December, and January in Latitude 71° N. and 78½° N.	D Number of Auroras from September to March in Latitudes 71° and 78½° N. and 70½° S.
1 A.M.	−12.8	−37	43	210
2	−16.2	−45	37	187
3	−21.0	−55	33	148
4	−23.1	−49	43	154
5	−24.8*	−33	41	124
6	−23.2	−22	33	77
7	−20.7	−14	27	60
8	−19.9	−28	13	26
9	−13.3	−51	18	36
10	− 7.0	−64*	15	30
11	+ 7.8	−44	15	30
12 Noon	+19.9	− 6	14	28
1 P.M.	+27.1	36	16	32
2	+29.2*	70	24	48
3	+24.7	95	42	84
4	+19.4	96*	49	102
5	+16.4	88	55	127
6	+15.9	63	61	151
7	+14.4	40	68	208
8	+12.9	21	67	255
9	+ 7.9	− 1	64	269
10	+ 1.1	− 7	61	263
11	− 5.6	−12	57	258
12 Midnight	−10.6	−26	42	210

to illustrate the matter, using figures given in articles in the Encyclopædia Britannica, but arranging them in a new way. Column A shows the average amount by which the *north* end of the magnetic needle is deflected from its usual position at six stations in the northern hemisphere at each hour of the day. A minus sign indicates a deflection to the east and a plus sign to the west. The eastward deflection is at a maximum not far from five o'clock in the morning. It slowly declines until ten, when a westward deflection begins. This reaches its maximum about two o'clock. The exact hours vary from station to station, but in the northern hemi-

sphere the maximum westward deflection regularly comes early in the afternoon. In the southern hemisphere similar diurnal variations take place, but there it is the southern end of the magnet which is deflected toward the west. In other words, in latitudes above 40° or 45°, where the magnetic forces are comparatively strong, the compass swings back and forth almost as if the centers of magnetic action shifted slightly westward when the sun is above the horizon and eastward when it sinks below.

Column B shows how the strength of the horizontal magnetic force varies at the same six stations. The force is well below normal until the sun almost reaches the zenith. Then it strengthens, reaching a maximum at three or four o'clock, but declines again at night. The diurnal change in both the direction of the compass and the strength of the magnetic forces can hardly be due to light or heat, for it is strongest in high latitudes, where heat and light vary least during the twenty-four hours. Moreover, although the change is stronger in summer than in winter, there are places such as Kew and Greenwich where there actually appears to be a secondary minimum at midsummer, just when the sun's heat and light ought to be most effective in producing a maximum.

In Table II columns C and D show the diurnal variation of auroras. The first column shows the figures for the months of November, December, and January, at Jan Mayen and Thornsden in high polar latitudes. Column D shows the auroras from September to March at these two sites and in south latitude 70½°, where the *Belgica* wintered in 1898. In both columns there is a marked diminution in the number of auroras in the morning. At first sight this might seem to be due entirely to the fact that even in these latitudes the winter sun when on the meridian is so little below the horizon that it slightly illumines the sky and thus renders auroras invisible. That the illumination of the sky has an important effect in diminishing the visibility of auroras is suggested by the fact that in column C the hours from 6 A. M. to 6 P. M. account for only 349 auroras, while the hours from 6 P. M. to 6 A. M. account for 589. In column D the contrast between night and day is still greater, 754 against 2,363. Nevertheless, as appears in Table III, some agency aside from light causes a great preponderance of auroras in the afternoon compared with the forenoon. For instance, taking the figures for northern auroras from November to January, as shown on the left of Table III, we see in the first line that one hour before noon, that is, at 11 A. M., 15 auroras were observed, and at one hour after noon, 16, a difference of 1, or 7 per cent, in favor of the afternoon. Comparing 10 A. M. and 2 P. M. we find 15 auroras in the morning against 24 in the afternoon, a difference of 9, or 60 per cent, yet the light at 10 A. M. is no brighter than at 2 P. M. All the way through the table the hours after noon up to midnight show an excess over the corresponding hours before noon having the same amount of light. The maximum difference comes about 4 o'clock. The same is true in the other part of the

TABLE III—COMPARATIVE NUMBER OF AURORAS BEFORE NOON AND AFTER NOON IN HIGH LATITUDES

NUMBER OF HOURS BEFORE OR AFTER NOON	AURORAS IN NOVEMBER, DECEMBER, AND JANUARY IN LATITUDE 71° N. AND 78½° N.				AURORAS FROM SEPTEMBER TO MARCH IN LATITUDES 71° AND 78½° N. AND 70½° S.			
	A AURORAS BEFORE NOON	B AURORAS AFTER NOON	C AMOUNT BY WHICH B EXCEEDS A	D PERCENTAGE BY WHICH B EXCEEDS C	A AURORAS BEFORE NOON	B AURORAS AFTER NOON	C AMOUNT BY WHICH B EXCEEDS A	D PERCENTAGE BY WHICH B EXCEEDS C
1	15	16	1	7	30	32	+ 2	7
2	15	24	9	60	30	48	+18	60
3	18	42	24	133	36	84	48	133
4	13	49	36	277*	26	102	76	292*
5	27	55	28	104	60	127	67	112
6	33	61	28	85	77	151	74	96
7	41	68	27	66	124	208	84	68
8	43	67	24	56	154	255	101	66
9	33	64	31	94	148	269	121	82
10	37	61	24	65	187	263	76	41
11	43	57	14	33	210	258	48	23

table, where both the northern and southern hemispheres are used, and the entire period of darkness from September to March is included. So far as light and clouds are concerned there is no reason why the auroras shown in column B should be more numerous than in corresponding parts of column A. Apparently the aurora-producing force is more effective in the afternoon than in the morning, just as are the magnetic forces shown in Table II.

On the basis of the facts here stated and many others it seems probable that both auroras and magnetic disturbances are due to the electrical activity of the sun, and that the solar force is at a maximum when the sun is on the meridian. The maxima of auroras and magnetic force, however, are delayed from two to four hours after the sun has passed the meridian either because the ions or other carriers of electro-magnetic impulses travel more slowly than sunlight or because a certain amount of time is needed before they accumulate strength enough to display their greatest effect. The earth, at each revolution, is apparently subjected to an electro-magnetic strain or stress due to its changing position in respect to the sun. The stress is, of course, extremely slight. Nevertheless Dr. Veeder believed that it is sufficient to cause not only auroras and magnetic disturbances, but certain other effects which are discussed below.

In addition to the conclusions already stated as to auroras and magnetism, Dr. Veeder came to certain others which are by no means so widely accepted. He held that the electrical action of the sun is confined to certain meridians. He based this conclusion not on a study of the sun itself, but on a study of the periodicity of auroras. Having tabulated the auroras for each day for about two hundred years, he found by repeated approximations that they show a periodicity of 27 days, 6 hours, and 40 minutes. His result, though obtained independently, agrees within four

minutes with the average period of solar rotation as determined by Maunder from the study of sun-spots. Unfortunately Dr. Veeder published little of the details of his work. He did, however, publish an auroral table for the four years 1885 to 1888. From this I have prepared a periodogram covering 1,392 days divided into four nearly equal groups. It shows how the frequency of auroras on each day differs from the frequency on the first, second, and third days thereafter, and so on up to the 30th day after the day in question. The results are shown in Table IV and also graphically in

TABLE IV—PERIODOGRAM OF AURORAS SHOWING THE SOLAR ROTATION CYCLE

AURORAL DIFFERENCES

GROUP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16 *Days*
I	110	142	160	168	150	152	152	119	116	107	121	123	141	146	159	157
II	126	136	129	140	142	154	167	177	169	181	195	186	199	187	159	191
III	128	144	165	178	170	157	151	150	154	151	137	143	140	141	174	182
IV	142	146	170	150	160	157	163	192	187	208	205	189	187	184	160	154
Average	127	142	156	159	156	155	158	160	157	162	165	160	167	165	163	171

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	54	273 *Days*
I	158	170	175	177	164	165	144	124	111	104	109	...	...	...	117	107
II	160	145	155	151	150	177	181	174	157	141	124	...	...	...	151	199
III	187	188	164	168	156	136	125	126	132	132	128	...	...	...	141	166
IV	154	148	151	151	173	175	186	201	191	176	174	...	...	...	170	187
Average	165	163	161	162	161	163	159	156	146	138	134	148	162	167	146	165

Figure 1. If the auroras occurred without periodicity, the difference between the number of auroras on a given day and on succeeding days would increase with lapse of time until it reached a certain average from

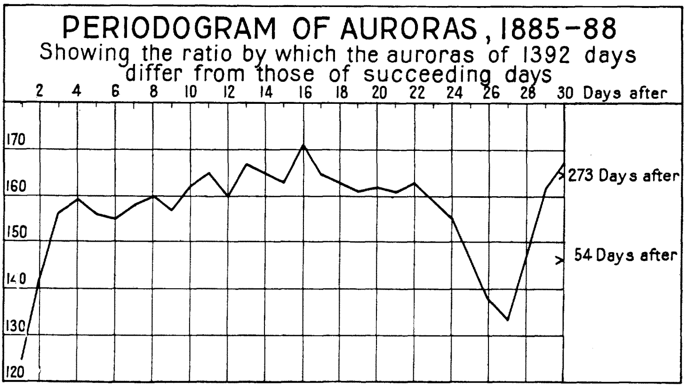


FIG. 1—Periodogram prepared from an auroral table by Dr. M. A. Veeder for the four years 1885-1888. The scale on the left is arbitrary; the arrowheads on the right indicate the height at which the curve would stand on the 54th and 273rd succeeding day (i. e. respectively at the end of two and ten solar rotations).

which there would be no important deviation. In other words, the curve of Figure 1 would at first rise rapidly and then gradually as it now does, and would at last become practically horizontal. Since each point in Figure 1 represents the average of nearly 1,400 individual cases, accidental

variations are reduced to negligible proportions. Accordingly the sharp drop culminating on the 27th day can scarcely be the result of chance. There must be a real periodicity. It has not seemed worth while to carry the periodogram beyond the 30th day, but as a further test I have compared each day with the 54th succeeding it, that is, with the day coming at the end of two solar rotations, and also with the 273rd day, that is, the day at the end of ten rotations. The height at which the curve would stand on those days is indicated on the right of the diagram.

The meaning of Table IV and Figure 1 seems to be that during the four years from 1885 to 1888 there was a decided tendency for the auroral conditions of the earth to repeat themselves at an interval of 27¼ days, corresponding to the period of the sun's rotation as seen from the earth. At the end of two solar rotations this same tendency reappears, but in a diminished form, while at the end of ten revolutions it has completely disappeared. This lends much probability to Veeder's conclusion that auroras and therefore presumably magnetic storms are connected with certain definite areas of the sun's surface, which sometimes retain the power of exciting electrical disturbances for several rotations, but do not retain it so long as ten solar rotations. It should be clearly understood, however, that the solar periodicity in terrestrial phenomena is by no means equally distinct at all times. It appears most unequivocally in periods such as 1885 to 1888 when there are comparatively few spots and especially when they are largely confined to one side of the sun. When the sun is highly disturbed the solar period is scarcely discernible either in auroras or in other terrestrial phenomena. This is not surprising, for at such times the sun's surface is in a constant state of agitation and a given condition persists only a short time.

The next step in Veeder's investigations was an attempt to determine the position on the sun's disk in which the active areas produce their maximum effect. He identifies this position with the eastern margin of the sun because he finds that on days when faculae or sun-spots appear there by rotation, auroras and magnetic disturbances are much more apt to occur than on other days. In order to test this matter Veeder took the magnetic curves of the Naval Observatory at Washington for the 783 available days between February 2, 1889, and April 2, 1891, and measured the difference between the length of the pen trace showing the declination and the corresponding horizontal time line. The difference between the two lines gives a good measure of the degree of disturbance. If the difference is less than one-twentieth of an inch, the day is classed as quiet. Otherwise it is classed as disturbed, and the intensity of the disturbance is reckoned in twentieths of an inch. Thus, although the scale is arbitrary, a reliable figure for magnetic disturbance is obtained for each day. More modern methods of reaching the same result are of course better, but that makes no difference in our conclusions.

For the period covered by the magnetograph tracings Dr. Veeder took the standard "Results of Photographic Observations" on the sun, which include data from Greenwich, India, and Mauritius, and from them made a table showing all the days when either a sun-spot or a facula was brought into view on the eastern limb of the sun by rotation. Unfortunately after gathering his data for both the sun and the magnetograph into a table which embodies a great amount of work, Dr. Veeder did not discuss his results at any length and did not analyze his table. I have analyzed it, with the result shown in Table V.

TABLE V—MAGNETIC STORMS, SUN-SPOTS, AND FACULAE
Based on data compiled by M. A. Veeder

		A No New Solar Phenomena	B New Sun-spots	C New Faculae	D Ratio B/A	E Ratio C/A	F Ratio C/B
Number of days		533	94	156	....	....	....
Days with no magnetic disturbance	No.	331	37	52	....	....	....
	%	62%	39%	33%			
Days with magnetic disturbance	No.	202	57	104			
	%	38%	61%	67%	1.61	1.76	1 09
Days with magnetic disturbance of 7 or more	No.	65	18	40			
	%	12%	19%	26%	1.58	2.17	1.38
Days with magnetic disturbance of 11 or more	No.	45	11	25			
	%	8%	12%	16%	1.50	2.00	1.33
Days with magnetic disturbance of 21 or more	No.	18	6	10			
	%	3.4%	6.4%	6.4%	1.88	1.88	1.00
Days with magnetic disturbance of 31 or more	No.	6	3	6			
	%	1.1%	3.2%	3.8%	2 91	3.45	1.19

Column A shows the number of days on which no new solar phenomena, either sun-spots or faculae, appeared on the sun's eastern limb as a result of being brought into view by that body's rotation. Column B includes the days when one or more new sun-spots appeared upon the sun's eastern limb, while C shows the days on which new faculae came into view. Following down the columns we see that on 62 per cent of the 533 days when no new solar phenomena appeared there were also no magnetic disturbances, but this was true on only 39 per cent of the days when new sun-spots appeared and on 33 per cent of the days when faculae appeared. In other words, as appears in columns D, E, and F, the percentage of days with magnetic disturbances was more than one and one-half (1.6) times as great when new sun-spots appeared as when none came into view and one and three-quarters as great (1.76) when new faculae came into view. Days with new sun-spots and new faculae are almost alike, but the faculae have a slightly greater frequency of magnetic disturbances, as appears in column F.

In the succeeding lines of the table it appears that in both columns D and E the ratios increase in general until they reach a value of 2.91 and 3.45. This means that during the period in question violent magnetic dis-

turbances at Washington occurred twice as often when sun-spots or especially faculae first appeared on the sun's eastern limb as on other days, while the most violent of all were three or three and a half times as likely to occur on such days as on days when no new solar phenomena were brought into view. Since the ratios in column F change but little, it appears probable that sun-spots and faculae bear a similar relation to magnetic disturbances, but the relation of faculae is on the whole the closer of the two. Perhaps the fact that faculae are not easily detected except on the sun's margin may explain the discrepancies not only between the diurnal changes of the earth's magnetic field and the sun-spot curve, but between the Scandinavian auroras and sun-spots as explained in connection with Table I. Faculae and sun-spots are closely related but do not have exactly the same variations. If faculae could be detected as easily as sun-spots the daily changes of the earth's magnetic elements might perhaps be found to agree almost exactly with changes in the sun.

On the basis of facts like those embodied in Table V Veeder concluded that magnetic and auroral disturbances on the earth depend largely upon changes in the sun's electrical field due to the appearance of electrically disturbed portions of the sun's surface upon the earthward side by rotation. He suggests that the outbreak of new disturbances or the increase of old ones upon the sun's earthward side may also produce an effect upon terrestrial phenomena, but he does not carry this idea to its logical conclusion. Hale has shown that "the magnetic fields of the sun-spots, which often reach intensities 50 times that of the sun's general field, are constantly changing in magnitude, as they are roughly proportional to the sun-spot areas." Ions shot from such electrified areas would reach the earth in greatest numbers when the areas were on the part of the sun most directly facing the earth. Hence the breaking out of a new disturbance in the central parts of the sun's visible disk would apparently influence the earth more than would the coming into view of a similarly disturbed area by rotation. Investigations which are not yet ready for publication seem to show that this is the case. Moreover, either the disappearance of a disturbed portion of the sun's disk by rotation or the dying away of sun-spot activity on the part of the sun's surface turned toward the earth would also be expected to disturb the electrical equilibrium of the earth. Hence Veeder's results would have been more convincing if he had investigated all changes known to have occurred upon the sun's surface instead of restricting himself largely to those upon the sun's eastern limb. Nevertheless those on the eastern limb appear on the whole to be the most important because rotation brings them suddenly into a position where they can at once influence the earth, whereas new spots commonly require some time in which to develop. New spots, however, sometimes appear with great suddenness. For example, Veeder cites an instance in 1881 when two photographs of the sun taken on July 25 at 3.58 P. M. and 4.47 P. M. show that in 49 minutes

there occurred an increase in spots amounting to 6,000,000,000 square miles, or about 3 per cent of the sun's total surface.

One more of Veeder's conclusions deserves emphasis. From a study of auroras he was led to believe that neither sun-spots nor faculae are in themselves the cause of terrestrial auroras and magnetic disturbances. He noted, as I have done in more recent cases, that sometimes when the sun is apparently quiescent without either spots or faculae the solar period in the terrestrial phenomena is peculiarly well marked. After two or three solar rotations, however, spots and faculae are apt to appear in the longitude which has apparently been producing the observed effects at each of its reappearances on the eastern margin. Hence Veeder believed that sun-spots and faculae are a *result,* not a cause, and that in this they resemble auroras and magnetic disturbances. Both the solar and terrestrial results seem to arise from certain peculiar conditions of solar activity which have thus far not been detected except from their results.

(B) Storms and Solar Changes

By M. A. Veeder

[After Dr. Veeder had come to the conclusion that auroras and magnetic disturbances are due to changes in the sun and are connected with particular parts of the sun's surface the next step was to see whether there is any connection between the solar changes and terrestrial meteorology. To show his line of thought it seems worth while to quote at length from a letter (a) and (b) and an unpublished article (c) in which Dr. Veeder gives a number of details. During the period from 1886 to 1889 daily international charts—now unfortunately discontinued—were published, showing weather conditions throughout the northern hemisphere. These make it possible to see at a glance what atmospheric activities were occurring in widely separated parts of the earth. The following pages give Dr. Veeder's comparison between these atmospheric activities and changes in the condition of the sun from October, 1886, to February, 1887, and in March, 1888. Similar details might be repeated indefinitely, but what is here given is enough to show how abundant is the evidence which finally led Dr. Veeder to the hypothesis set forth in Part II of this article, to be published in the next number of the *Review.*—E. H.]

(a) SOLAR AND TERRESTRIAL PHENOMENA OBSERVED FROM OCTOBER, 1886, TO FEBRUARY, 1887

[From a letter addressed to Gen. A. W. Greely, Chief Signal Officer, U. S. A., and dated Lyons, N. Y., May 7, 1888.]

October 3, 1886. Many small groups of faculae appeared by rotation.

In North America the anticyclone (30.40) enlarged greatly, the North Pacific Coast cyclone deepened (29.79 to 29.65), a small low (30.00) moved eastward. On the Atlantic coast the winds increased in force.

On the Atlantic Ocean. The cyclones between Newfoundland and Great Britain

were crowded together by enlargement of the surrounding anticyclones and were partly filled up (29.60 to 29.80 and 29.19 to 29.42). A severe storm not shown on the preceding map appeared off the coast of Norway, pressure 29.13.

In Europe. The anticyclone (30.40) enlarged greatly.

In Asia. A low, circumscribed by isobar 29.60, appeared. The Siberian anticyclone was crowded eastward and weakened (30.40 to 30.20). The Indian cyclone 29.60 was enlarged. Evidence of the formation of a low over the East Indies became apparent, the low itself coming fully into view on the charts for October 4 and 5.

The general effect of these changes may be summarized as an increase of barometric range as compared with the day preceding—anticyclones in general having been strengthened and cyclones likewise on the whole having increased.

October 6. An outbreak of spots occurred in the area of faculae which came into view October 3, also several groups of faculae appeared by rotation.

In North America. The North Pacific Coast low deepened (29.72 to 29.46). A low with isobar 29.80 appeared over southern California. The anticyclones remained steady.

On the Atlantic. Low (29.80) appeared over Gulf Stream with strong winds in that vicinity. Low over North Atlantic enlarged somewhat and deepened greatly (29.31 to 29.12). Anticyclone over South Atlantic [i. e. southern North Atlantic] steady but moved eastward.

In Europe. Anticyclone (30.20) diminished in size.

In Asia. Cyclone in western part deepened slightly (29.33 to 29.26). The anticyclone enlarged greatly and deepened (30.00 to 30.20). Severe storm with pressure 29.14 appeared off the Pacific coast.

In this case again the barometric range is increased by the formation of new lows and increase in depth of those already existing. The anticyclones, however, remain comparatively steady, the only well-marked increase being in Asia. These conditions persist very steadily until the next date.

October 9. A group of faculae appeared, and there were rapid changes in the group of spots near the sun's meridian.

In North America. The Pacific Coast low (29.80) moved into the Rocky Mountain region and deepened (29.80 to 29.60, Oct. 10). Storm with isobars 29.60 appeared over the Gulf of Mexico. New anticyclone 30.20 appeared in the Northwest. Gulf Stream storm 29.80 filled up by increase of eastern anticyclone (30.20).

On the Atlantic. Anticyclone (30.20) enlarged greatly. North Atlantic storm became more severe (29.20 to 28.80).

In Europe. Anticyclone 30.40 enlarged and moved eastward, filling up the cyclone over western Asia.

In Asia. The Siberian anticyclone enlarged and increased (30.20 to 30.60 on Oct. 10). On October 10 the cyclone off the coast of Asia deepened (29.80 to 29.60), and the anticyclone moved eastward, making the gradient very steep.

Again there is an increase of barometric range, cyclones and anticyclones generally throughout the northern hemisphere showing coincident sudden changes of like character.

October 14. An outbreak of spots of considerable size occurred near the sun's meridian.

In North America. A storm of great severity suddenly developed (29.60 to 29.10). The eastern anticyclone increased (30.00 to 30.20). The western anticyclone remained steady.

On the Atlantic. North Atlantic cyclones underwent rapid changes, a very severe storm (28.65) apparently forming west of Ireland. Another low, 29.57, appears in the South Atlantic. The South Atlantic anticyclone enlarged somewhat.

In Europe. The anticyclone 30.20 moved eastward, increasing in area. A low, secondary to the North Atlantic storm, formed with isobar 29.80 on October 15.

In Asia. The Siberian anticyclone deepened (30.20 to 30.40). The storms attending this outbreak upon the sun were very remarkable in many respects.

October 16. The spot group that formed on October 14 underwent rapid changes, many spots forming in two groups.

In North America. The anticyclone enlarged and increased in depth (30.40 to 30.60). The cyclone deepened from 29.42 to 29.29.

On the Atlantic. The anticyclone enlarged in area and increased in depth (30.20 to 30.60).

In Europe. The cyclone central over Great Britain remained steady (28.68 to 28.69).

In Asia. The western anticyclone (30.40) and the eastern anticyclone (30.20) united, forming one very large anticyclone with isobar of 30.60 at center.

October 23 and 24. Two small spots and a group of faculae came into view by rotation.

In North America. Low formed on North Pacific coast (29.58 on Oct. 25). Low formed east of Rocky Mountains (29.49 on Oct. 23). Two anticyclones formed (30.20 on Oct. 23) and deepened (30.40 on Oct. 24), uniting into one on October 25 (30.60).

On the Atlantic. Cyclone near Newfoundland deepened (29.80 to 29.56 on Oct. 23). West Indian cyclone deepened (29.80 to 29.50 on Oct. 23). Anticyclone (30.20) remained steady.

In Europe. Cyclone over Spain (29.66) remained steady until October 25. Cyclone formed north of Norway (29.71 on Oct. 25). Two anticyclones formed and increased (30.40 to 30.60).

In Asia. Siberian anticyclone increased (30.20 to 30.40) and moved eastward, followed by small cyclone (29.80) on October 23. The conditions thus established remained pretty steady until the next date.

October 30. Faculae came into view by rotation.

In North America. Anticyclone (30.20) enlarged. North Pacific coast cyclone increased in size, moving southeast. Cyclone (29.76 on Oct. 31) formed over Middle Atlantic coast.

On the Atlantic. North Atlantic low deepened (29.70 to 29.15). The anticyclone enlarged and deepened (30.20 to 30.40).

In Europe. The anticyclone diminished somewhat in depth and increased slightly in area (30.80 to 30.60).

In Asia. The cyclone increased slightly in depth (29.63 to 29.47) and moved eastward. The Siberian anticyclone diminished somewhat in depth (30.60 to 30.40) but increased in area.

It happened that observation was poor on October 29. It is possible that portions of the solar disturbance of October 30 were in view then.

During November, 1886, there was a well-marked period of sun-spot minimum. Hence this month is specially interesting. Auroras were numerous during the first week. Although but one solar disturbance, a group of faculae on the 4th was observed coming into view by rotation.

November 4. A group of faculae of small extent appeared by rotation.

The anticyclones generally increased in extent and depth, and the cyclones were but little affected.

November 7. A group of faculae was observed close to the sun's eastern margin.

A severe storm (29.03) formed over the eastern United States, and the Atlantic anticyclone enlarged somewhat. Otherwise the conditions did not change materially.

On November 8 and 9 also small groups of faculae appeared by rotation. The

changes in barometric pressure were, however, relatively unimportant. The comparative evenness of barometric pressure throughout the northern hemisphere, particularly on November 11, is noteworthy. There was not entire calm—but both sun and atmosphere were remarkably quiescent, and that, too, at a time when storms are usually most severe. This quietude was soon broken in upon, however.

November 13 and 14. Very bright faculae appeared upon the sun's margin by rotation.

In North America. The anticyclone enlarged and increased (30.40 to 30.60). A severe storm (29.41) formed on the South Atlantic coast and deepened to 29.14 on November 15.

On the Atlantic. The cyclone near Great Britain deepened from 29.45 on November 12 to 29.11 on November 15. The anticyclone remained steady. The Siberian anticyclone remained nearly steady.

In Europe. A low (29.40 on Nov. 14) formed, secondary to the Atlantic cyclone.

November 16. Several spots formed in the group of faculae that came into view November 13 and 14.

In North America the western cyclone from Lower California advanced rapidly eastward, with pressure at the center as low as 29.10 on November 19. In the China seas also a storm (29.48) developed. There were some changes in the anticyclones over the United States and the Atlantic, otherwise the conditions remained but little changed.

From November 21 until November 29 there was another period of great quietude on the sun. Throughout the northern hemisphere during this period atmospheric pressure was very evenly distributed. The only storm of importance noted moved from the Pacific coast on November 20 and passed rapidly across the United States, with quite low pressure at the center (29.10 on Nov. 23), following almost the precise track of the storm of the week before. Several instances of storms succeeding one another in the same track at short intervals have been recorded. The evenness of distribution of barometric pressure, particularly on November 27 and 28, is noteworthy. All the storms previously running had almost exhausted themselves. On November 29, however, a fresh impulse of some sort was given, the faculae of November 4 returning by rotation.

November 29. Faculae came into view by rotation.

In North America. The cyclone deepened (29.74 to 29.39).

In Europe and on the Atlantic. The anticyclone developed largely in extent, and the storm near Norway became severe, pressure falling from 29.30 on November 28 to 28.74 on November 30.

December 1, 2, 3, and 4. No observation.

December 5 and 6. A group of faculae appeared by rotation.

In North America. The anticyclone divided, and a low (29.80) formed over South Atlantic coast.

On the Atlantic. The cyclone deepened (29.00 to 28.56 on Dec. 7). The anticyclone changed but little.

In Europe. Little change noted.

In Asia. Anticyclone fluctuated somewhat.

December 8 and 9. Faculae and spot appeared by rotation.

In North America. North Pacific low remained steady (29.21). The anticyclone (30.40) enlarged.

On the Atlantic. The low over the Gulf Stream moved northward, increasing in depth, 29.53 on December 8, 28.80 on December 10. The low over Great Britain deepened (28.56 to 28.02). The anticyclone over the South Atlantic remained steady.

In Europe. Cyclone deepened. Otherwise no marked change.

In Asia. Cyclone on Pacific coast deepened (29.80 to 29.40). Otherwise no marked change.

There were many changes in the spot group that appeared on December 8 and 9 during its entire transit. It disappeared on December 19, leaving the sun very tranquil.

On December 20 the comparative evenness of distribution of atmospheric pressure is again noticeable. It did not last long, however.

December 21. A small spot, the first of an extensive group, appeared by rotation.

Atmospheric pressure remained quite steady except in the North Atlantic, where the low deepened from 29.51 to 28.93.

December 24. A group of spots, one very large, appeared by rotation.

In North America. A low formed in the Great Lakes region (29.80 to 29.40 on Dec. 25). Anticyclone (30.40) enlarged.

On the Atlantic. Low deepened from 29.40 on December 23 to 28.93 on December 25. Secondary low, 29.80, also formed in South Atlantic.

In Europe. A low, 29.51, and a low, 29.80, formed secondary to the Atlantic depression.

In Asia. The Siberian anticyclone enlarged.

During its entire transit this group of spots underwent numerous changes which it would be tedious to follow in detail. Another spot also came into view on December 27. On the basis of the hypothesis here under consideration the last week of December and the first days of January should have been a period of severe storms; which was the case. The barometric range on December 31 was remarkable, the North American anticyclone attaining 31.00 and the North American cyclone, 28.80.

January 5, 1887. Considerable faculae appeared by rotation.

The most notable coincident change was the deepening of the North Atlantic cyclone from 29.00 to 28.46, the isobars becoming numerous and crowded. A low (29.63) formed off the South Atlantic coast of the United States and another low (29.52) on the Pacific coast of Siberia.

On January 6 and 7 other groups of faculae came into view. Coincidently the anticyclones generally were strengthened.

No satisfactory observations were had until January 15, when the sun was found to be comparatively clear, groups of faculae alone being detected in the western quadrant.

January 17. Faculae were observed coming into view by rotation.

In North America. The North Pacific coast cyclone deepened from 29.82 to 29.29. Another low moved rapidly eastward, increasing in depth from 29.51 to 29.16 (28.93 on Jan. 18). The anticyclone increased from 30.40 to 30.60.

On the Atlantic. North Atlantic low deepened from 29.00 to 28.40, isobars becoming numerous and crowded. A secondary low (29.35) formed east of Newfoundland. The anticyclone increased in size and depth (30.20 to 30.40).

In Europe and Asia. The conditions were not materially changed.

January 20. Considerable faculae observed close to sun's eastern limb.

In North America. North Pacific low 28.85 (was 29.27 Jan. 19). Eastern low moved rapidly toward Gulf of St. Lawrence and deepened (29.08 on Jan. 21).

On the Atlantic. North Atlantic cyclone deepened, becoming 28.69 on January 21 (had been 29.35 on Jan. 19). Isobars became very numerous and much crowded.

January 24. Large and very active spot group, which underwent numerous changes during its entire transit, came into view on January 24 and 25. From January 24 to February 5 storms were severe. On January 28 and 29 the barometer registered 28.60 in the North Atlantic and likewise again on February 2. On February 3, 4, and 5 the barometer attained 31.00 over British America.

February 2. A group of active spots came into view by rotation. The cyclone over the North Atlantic became more intense, the isobars more crowded, and the pressure lower (28.54). On February 3 coincidently pressure had risen to 31.00, and on February 4 it attained the remarkable height of 31.20.

On account of cloudiness the observation of faculae became difficult, and there were few spots visible until February 17, hence details cannot be given for this period.

February 17, 18, and 19. A group of large spots appeared by rotation.

Cyclone moved rapidly eastward in the United States, deepening from 29.60 to 29.03.

The North Atlantic cyclone deepened from 29.39 to 28.84, and the isobars became numerous and crowded. In southeastern Europe a low (29.62) formed. The cyclone east of Siberia was deepened also (30.00 to 29.80).

(b) CONCLUSIONS

In general it may be remarked that in October the disturbances were quite evenly distributed on all sides of the sun. At certain intervals, however, well-defined impulses affecting the atmosphere very strongly over wide areas were imparted. In November there were two well-marked periods of quietude both in the sun and coincidently in the atmosphere. In December, January, and February there were two extensive areas on opposite sides of the sun that were actively disturbed. It was only for brief intervals that one or the other of these was not upon the earthward side of the sun, and storms were almost incessant. At certain times periods of well-marked increase occurred. In March, during the first half of the month, there was active disturbance, but it was ill-defined and difficult to trace. During the last half of the month the conditions were more easy of observation, several well-marked impulses being imparted to the atmosphere coincidently with characteristic solar conditions.

In short, it is the phenomenon known as the atmospheric "surge"[1] that seems to bear the closest relation to the varying condition of the sun. The rapid fluctuations of barometric pressure, sometimes remaining stationary for days in a single locality, resemble aërial tides and do not appear to be traceable to any well-defined terrestrial cause. They occur where aqueous vapor is abundant and where it is lacking. Not infrequently they are apparent during the same day throughout the entire area covered by observations. There must be some cause for them affecting the entire earth. A close examination of the record of solar conditions after the manner that has been suggested will, it seems to me, afford a key to this, one of the most difficult problems connected with meteorology.

From the above summary it appears that whenever active changes are in progress upon the sun the range of barometric pressure increases, temperature and pressure gradients become more steep, and in short all the phenomena attending storms become more intense. It is not possible, however, to use the information thus secured for purposes of weather prediction further than to note the fact that a period of severe storms may be at hand, their locality being impossible to determine save imperfectly by means of the synoptic charts.

As regards the solar observations certain points must be noted. It is

[1] Arctowski's "pleions."—E. H.

the brightness and extent of the faculae rather than the dark spots that must be taken into account in forming an opinion in regard to the activity of a solar disturbance. It may be noted also that for months together disturbances upon certain parts of the sun are more energetic, being attended by auroras or magnetic and electrical phenomena to a far greater extent than those located elsewhere. It is only by keeping a careful record during successive periods of the sun's revolution on his axis that this feature can be made manifest. At times for months together it may afford the means of forecasting periods during which storms will occur of peculiar intensity.

It is to be understood that these solar impulses constitute but one element in the problem. The influence of climate and season in different parts of the earth causes different effects to follow from the same impulse in different localities.

I have given but one phase of the subject in this summary. The proof might be greatly strengthened by taking into account the subject of auroras, magnetic storms, and thunderstorms, which have been the topic of previous communications.

As regards the nexus, or bond of union, between these special solar and atmospheric conditions, it is difficult at present to state any hypothesis that would not perhaps be soon overturned by a further study of the facts. It is not yet time to theorize, but much, it seems to me, may be hoped to be learned by collecting facts along the lines that have been indicated in the foregoing hasty outline, which has been brought together very imperfectly at intervals in the midst of other duties.

(c) THE NEW YORK BLIZZARD AND ITS ATTENDANT CONDITIONS FROM MARCH 6 TO MARCH 15, 1888

The study of a well-marked period like that during which the New York blizzard occurred may be expected to yield interesting results.

The Solar Conditions. On March 7 a disturbed area which contained a small spot on March 9 came into view by rotation. On March 9 another group of several spots appeared. The faculae in their vicinity presented a glowing and rose-tinted appearance and underwent rapid changes. These disturbances were visible until March 20, no other of any importance appearing except on March 15.

Auroras and Thunderstorms. On March 7 auroras were seen in Dakota, Iowa, Massachusetts, Michigan, Minnesota, New Jersey, and Wisconsin, being especially brilliant in northern Michigan. No thunderstorms were reported. Upon subsequent dates they were faint and rarely seen, until March 15, when they again became widely prevalent, on that date also no thunderstorms being reported. On March 9, when spots appeared as above, thunderstorms became widely prevalent at numerous points

throughout the southern United States, extending within forty-eight hours from California on the west to Florida on the east, faint auroras only being reported at one or two stations in the Northwest.

This reciprocal relation between thunderstorms and auroras has been noted in well-marked instances repeatedly. It may serve to explain why in certain instances the magnets remain quiet when large solar disturbances appear, atmospheric taking the place of earth currents.

It is noteworthy also that the outbreak in each instance followed at once upon the appearance of the solar disturbance by rotation. It is very remarkable that the aurora should reach its height within a single day and then decline, although the solar disturbance originating it remains upon the earthward side of the sun for nearly two weeks. The same is true also of disturbances of magnetic declination. It may be noted in general that auroras and magnetic disturbances appear before the solar disturbance coincident with them has reached the sun's meridian. A brilliant group of faculae, especially if it have a glowing rosy tinge, is more likely to be attended by magnetic or electrical phenomena than is a single dark spot having a typical form and penumbra. The most active disturbance of all is the rifted and broken collection of small spots with brilliant faculae in their vicinity, which was the character of the disturbance of March 9.

Magnetic Conditions. On March 6 the magnet at Washington was almost perfectly quiet. On March 7 very active movements began and, as is usual, were most pronounced during the night. The force that produces auroras and magnetic storms appears to be repulsive, producing these effects upon the darkened side of the earth away from the sun. Perhaps it will be found that thunderstorms prevail upon the side of the earth toward the sun under such circumstances, the full force of the variation of tension being limited to a few hours only and declining rapidly after the first impulse. A period of thunderstorms as well as auroras is usually brief. The effects of sustained tension would probably be cognizable under some different form of manifestation from those due to rapid variation of tension.

It is noteworthy that the magnet at Los Angeles was put in motion on March 7 at precisely the same instant as those at Toronto and Washington. But the movements were less vigorous, as appears to be the rule in that locality.

Earthquakes. Earthquake shocks were felt at 8 A. M. at Pasadena, Cal., on March 7; in Herzegovina on March 8, and in Norway at 2 A. M. on March 12. Earthquakes as a rule become more frequent during the periods when auroras and magnetic storms are prevalent.

Atmospheric Movements. Following the period of thunderstorms and auroras there appears to be a period when secondary phenomena due perhaps to sustained tension increase. It is at this time that anticyclones become most prevalent. In any event the period under consideration will

be found very interesting because of the remarkable atmospheric conditions everywhere prevalent during its continuance.

At 7 A. M. on March 7 in the United States the atmosphere was very quiet, there were no strong winds, and the isobars were far apart and few in number. On March 8 a decided change had become apparent, isobars and isotherms becoming more and more numerous and crowded, culminating on March 11 in the famous New York blizzard, which appeared totally unannounced.

That this blizzard was not a local affair but formed a part of a world-wide disturbance is shown by the fact that upon the same day a storm fell upon England totally unannounced by the Weather Department. The violence of this storm may be estimated by such facts as the following: At Pembroke, England, the barometer fell to 28.57. At 5 P. M. at Greenwich wind pressure rose to 31 pounds to the square foot, equal to a velocity of 80 miles an hour. At Rousdon Observatory, Lyme-Regis, a Robinson standard cup anemometer recorded the following velocities: 64 miles from 11 A. M. to 12 M.; 67 miles from 12 M. to 1 P. M.; 71 miles from 1 to 2 P. M.; 73 miles from 2 to 3 P. M.; 63 miles from 3 to 4 P. M.

On March 12, 13, and 14 a storm appeared upon the Pacific coast of the United States with wind velocities from 50 to 60 miles an hour at Ft. Canby, Washington Territory.

On March 10 also the wind rose to 50 miles an hour at Galveston, Texas.

On March 9 a storm that left Newfoundland on March 1 experienced a marked increase of energy, the barometer falling very low, with force of wind 12.

On March 13 in western Australia the barometer suddenly fell 0.20 inch in a cyclonic area moving eastward along the south coast. On that date also a tidal wave reached New Guinea and New Britain. At the latter place it is supposed to have risen 40 feet. On March 15 the wind attained a velocity of 55 miles at Sydney, Australia. On Lake George in that country the observer remained windbound for several days.

Other details might be given showing the violence and extent of the atmospheric commotion in many localities throughout the earth at the time of the New York blizzard. It is a curious fact that this storm revived again on March 15, it having moved eastward with decreasing force after having devastated New York and vicinity. It will be observed that March 15 was the date of the appearance of another outbreak upon the sun, attended by auroras and magnetic storms. It is stated also that there was a revival in the energy of a storm lingering in Scotland on that date also.

It is by continued study of the natural grouping and association of phenomena, particularly during such periods as that in question, that we may hope to gain an insight into their true relations. My purpose in this hasty sketch is to illustrate the method rather than to justify conclusions.

(To be concluded)